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INTERPRETATION OF SOLAR WIND ION COMPOSITION MEASUREMENTS FROM ULYSSES

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1. Summary

1.1 Scope of the Investigation

Ion charge states measured in situ in interplanetary space carry information on the properties of the solar wind plasma in the inner corona. This information is, however, not easy to extract from the in situ observations. The goal of the present proposal is to determine solar wind models and coronal observations that are necessary tools for the interpretation of charge state observations. It has been shown that the interpretation of the in situ ion fractions are heavily dependent on the assumptions about conditions in the inner corona.

1.2 Progress Made

There are three fields important to the interpretation of minor ion charge state measurements that we have concentrated on during the past year. These are 1. Modeling of the charge state ratios of a number of ions commonly measured in situ, 2. Modeling of minor ion outflow properties, and 3. Investigating the effect of hot protons on spectral line diagnostic in the inner corona.

1. The interpretation of charge state observations in interplanetary space is only possible in the context of models since the ion ratios are extremely sensitive functions of the electron density, electron temperature and minor ion outflow speeds. In past studies it has always been assumed that the minor ion outflow speeds in the inner corona are of the order of a few km s^{-1} or even less. In our study we investigated whether higher ion outflow speeds can also be in agreement with the observed ion ratios. In this study we evaluated the uncertainties in the calculated ion ratios due to uncertainties in atomic data, the possible presence of non-Maxwellian electron velocity distribution functions and mass outflows. Assuming a Maxwellian velocity distribution function we showed that the high minor ion outflow speeds of the order of the O^{+5} outflow speed (about 200 km s^{-1} at 2 R_S) recently derived from Doppler dimming experiments in a polar coronal hole region (Kohl et al. 1996) are also in agreement with charge state observations.

The models presented in Figures 1a to c do not contradict any of the existing observations. The combination of flow speed, electron density and temperature chosen for these two examples yield basically the same C, O Si and Fe ion ratios. Considering the uncertainties inherent in the models and the measurements, the calculated ion ratios agree rather well with the measured values. We concluded that high flow speeds in the inner corona, like the ones estimated from observations by Kohl et al. (1996), can presently not be excluded on the basis of the ion charge state observations. Since the calculated ratios are as close to the measured ones as can reasonably be expected considering all sources of uncertainties, we also conclude that one can not presently make predictions about the ion flow speeds in the inner corona from the ion charge states. Note that in this study we have assumed that all ions flow with the same speed; however, this assumption may well break down depending on the heating and acceleration mechanisms.

The coronal model recently presented by Feldman et al (1996), on the other hand, requires electron temperatures much higher than the ones usually observed in coronal hole regions. It remains to be seen whether this will change if one in addition to high ion outflow speeds also assumes non-Maxwellian velocity distributions.

2. Using a three fluid model of the solar wind we have investigated the flow properties of oxygen ions in the solar wind. It was found that by choosing appropriated heating functions for all the particles (electrons, protons and minor ions) solutions where the minor ions flow an Alfvén speed faster than the protons in interplanetary space can easily be achieved. In these type of solutions the minor ions have a tendency to be faster than the protons already very close to the sun. The distance where the protons are overtaken by the ions is typically at 2 R_S, a distance that could still be below the freezing in distance for the different charge states.

3. As shown above, the in situ charge states depend on electron density, electron temperature and ion outflow speed. The better one can constrain these parameters in the inner corona by remote observations, the more complete will the picture be that one can derive from the in situ charge states. We have therefore also devoted some time to think about possible mechanisms that might affect the interpretation of spectral line diagnostics in the inner corona. That was the motivation for studying the effect of high proton/heavy ion temperatures in the inner corona. We found that the line ratio temperature diagnostics could be affected by 15 to 20 %, whereas the effect on density sensitive lines could be up to a factor of 2. As examples we choose some of the commonly used spectral lines. The effect of the high proton temperatures depends on the spectral line.

1.3 Future Plans

For the next year we plan to investigate in detail the effects of non-Maxwellian distribution functions in the presence of high coronal outflow speeds on the interpretation of the ion charge state observations. We intend to approximate the non-Maxwellian distribution functions with a series of Gaussians. A computer code has been developed by Raymond et al. for the interpretation of spectral lines in the inner corona.

We will also continue our efforts to develop computer models to describe the minor ion outflow properties, and to use the results of these models in a self-consistent manner in the interpretation of the charge state observations. These calculations will include a larger number of ions typically observed by in situ instruments.

We will participate in the observations of minor ions in the inner corona with the UVCS instrument on Soho. This instrument is to date the only instrument that can provide some of the minor ion constraints, mainly flow speeds, that are necessary for the interpretation of the in situ charge state observations.

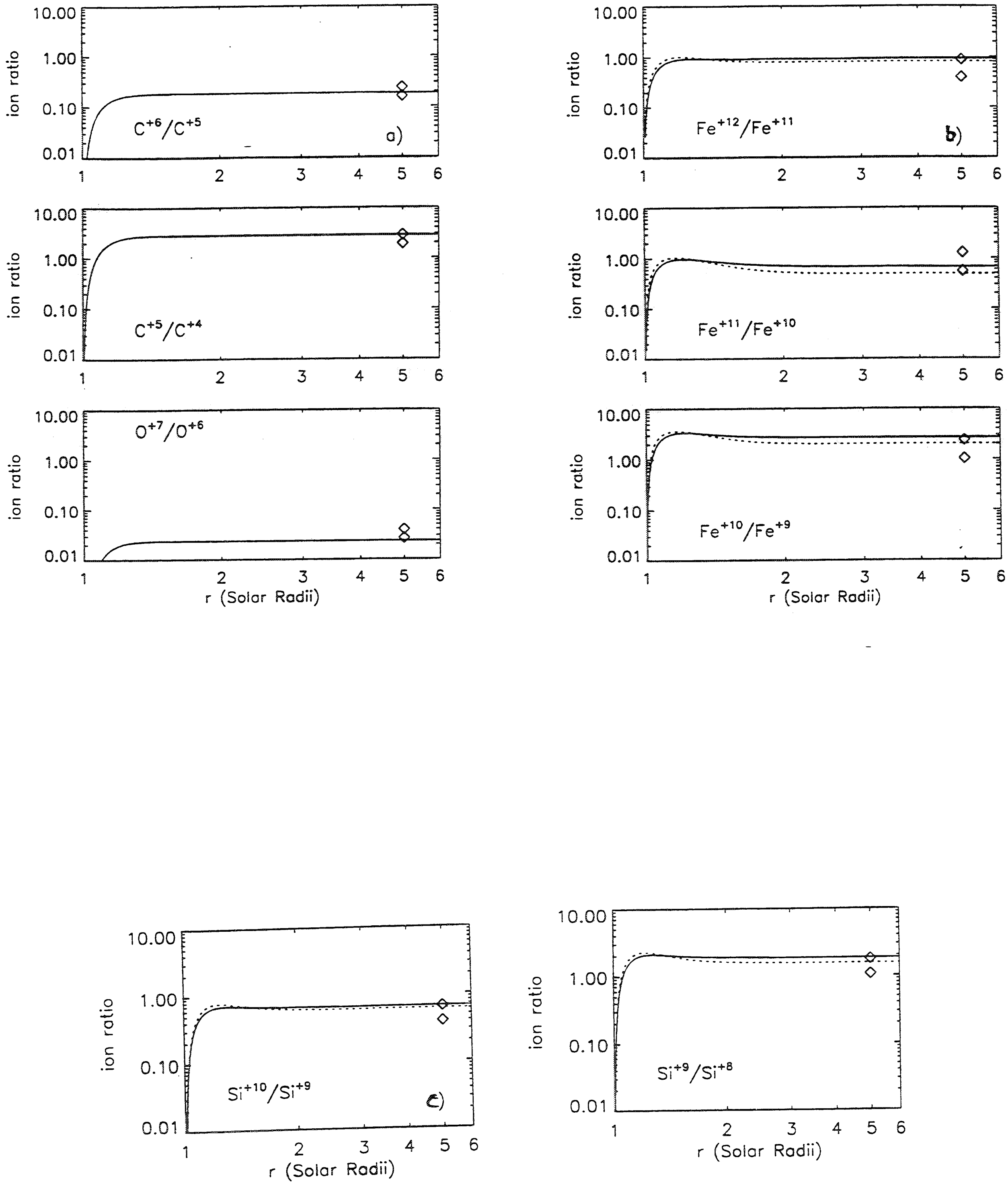

Figure 1: Calculated ion fractions for the ion charge states most commonly measured in the solar wind a) C and O, b) Fe, and c) Si. The measured values (from Geiss et al. 1995) are given as diamonds. Upper and lower estimates on the measured values are derived when error estimates are also included.

2. Publications in Journals and Proceedings

1996

1. R. Esser, S. R. Habbal, W. A. Coles and J. V. Hollweg, Hot protons in the inner corona and their effect on the flow properties of the solar wind, *J. Geophys. Res.*, accepted, 1996.

2. N. S. Brickhouse and R. Esser, Effects of high proton temperatures on spectral line diagnostics in the source region of the high speed solar wind, *Astrophys. J.*, in press, 1996.

3. R. Esser, R. J. Edgar and N. S. Brickhouse, High minor ion outflow speeds in the inner corona and observed ion charge states in interplanetary space, *Astrophys. J.* submitted, 1996.

4. R. Esser and N. S. Brickhouse, Interdependence of solar wind models and solar wind observations, in Proceeding of the workshop *Scientific Basis for Robotic Exploration Close to the Sun*, ed. S. R. Habbal, AIP, in press 1996.

5. J. V. Hollweg and R. Esser, The Solar Corona and the Solar Wind: Theoretical Issues, Review paper in Proceeding of the workshop *Scientific Basis for Robotic Exploration Close to the Sun*, ed. S. R. Habbal, AIP, in press 1996.

6. X. Li, R. Esser, S. R. Habbal, and Y.-Q. Hu, Influence of heavy ions on the solar wind, submitted to *J. Geophys. Res.*, 1996.